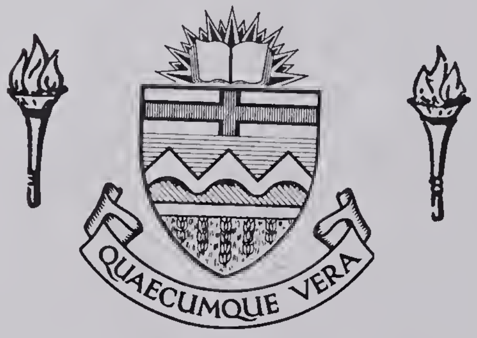
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THE UNIVERSITY OF ALBERTA

GROWTH PATTERNS, RELATIONSHIPS AND GROWTH COEFFICIENTS OF TISSUES IN BEEF CATTLE

by

HARI MOY MUKHOTY

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Growth Patterns, Relationships and Growth Coefficients of Tissues in Beef Cattle" submitted by Hari Moy Mukhoty, B.V.Sc. & A.H., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

An investigation was undertaken to study the influence of breeds, sexes and nutritional effects on the growth of muscle, bone and fat in cattle. Total dissection data was obtained from 91 steers, 59 bulls and 18 heifers representing 8, 6 and 2 breed groups, respectively. Totals and proportions of muscle, bone, fat and muscle/bone ratio differed significantly ($P < 0.01$) among breed groups of bulls and steers indicating different patterns of tissue growth in various groups. Conversely, the two breed groups of heifers did not differ significantly in carcass composition which indicated similar tissue growth patterns.

Sex showed a marked influence on carcass composition through its influence on the onset of the fattening phase. Heifers fattened at lighter live weights than steers and steers at lighter weights than bulls. Bulls showed a greater impetus for muscle growth followed by steers then heifers. Bulls were favoured in muscle/bone ratio compared to steers and steers compared to heifers.

A nutritional effect on carcass composition was observed in young growing Jersey bull calves fed rolled barley vs. those fed rolled oats. Carcasses from those fed barley contained more fat, less lean and a similar proportion of bone compared to those fed oats. This is explained by the fact that barley contained more energy per unit weight than oats and the extra energy over and above maintenance augmented deposition of fat.

The simple regression and correlation coefficients involving muscle, bone, fat, muscle/bone ratio and cold carcass weight were calculated to find an index of carcass composition which would be either almost independent of weight or stage of development, or one in which adjust-

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TABLE OF CONTENTS

EXPERIMENTAL

Page

LIST OF TABLES

APPENDIX

INTRODUCTION

The phenomenon of growth is one of the most important processes in practical agriculture. In fact, almost the whole of agricultural production depends on some aspect of the growth process. Improvement in meat animal production requires growing animals which produce the best type of carcass at a minimum expenditure. From the standpoint of the producer as well as the consumer, the most desirable carcass is one that contains only enough bone to give it form, enough fat for palatability or to satisfy consumer and market conditions and contains a maximum proportion of lean meat.

A method is needed to accurately assess the pattern of tissue growth in beef cattle and to relate this to carcass composition in the carcass. A large amount of research effort has been directed towards the development of simple objective measurements in beef cattle to estimate reliably the carcass merit. More effective prediction of, and selection for growth and body composition might be realized if the growth patterns of the separate tissues were identified. This would also facilitate the possibility of exercising control, by genetic and environmental means, thus influencing the production of animals to meet any specific requirements.

Attempts have been made in this research project to study the normal growth patterns of tissues in beef cattle and the various genetic, physiological and environmental factors which might influence these patterns. Another objective of this study was to investigate the feasibility of establishing the basis for comparing differences in carcass composition among breed groups and among cattle from various experimental treatments.

REVIEW OF LITERATURE

I. Total Anatomical Dissection Technique

A. Historical Aspect

Total anatomical dissection technique involves the physical separation of a commercially standarized slaughtered carcass into individual muscles, bones, connective tissues, ligaments and dissectable fatty tissues which could be classified as subcutaneous, intermuscular and internal (body cavity) fat. The commercial carcass, within a narrow range of variation from country to country, comprises the eviscerated body from which various parts were removed at the following points:

(i) Thoracic limbs - at the carpo-metacarpal articulation.

(ii) Pelvic limbs - at the tarso-metatarsal articulation.

(iii) The head - at the atlanto-occipital articulation.

(iv) The tail - at the first intercoccygeal articulation.

(v) The skin - completely removed. A few bands of cutaneous trunci and cutaneous ombrachialis muscle, from the dorsal region of the body, are removed with the skin.

Separating the beef carcass into lean, fat and bone was first done in the early 1900's by Trowbridge et al. (1919) at Missouri. The reader is referred to Bratzler (1958) for a more complete review of the history of carcass evaluation and to Bray (1963) for terminology. This separation technique was first used on lambs by Hammond (1932) to show the effect of plane of nutrition on the deposition of fat in the carcass. Hammond's separation technique was used by many of his students in various species of domestic animals. These included studies by Pálsson (1939, 1940) and Pálsson and Vergés (1952a, b) on lambs, Wallace (1948a, b, c) on sheep, McMeekan (1940a, b, c, 1941) on pigs, Wilson (1958, 1960)

on goat and also by Wilson (1952, 1954a, 1954b) on poultry. Investigations involved the influence of breed, sex and nutrition on the development of tissues and relative changes in the carcass composition. A more complete total anatomical dissection technique was developed by Walker (1961) and Butterfield (1963) and used by Berg and Butterfield (1966, 1968), Butterfield and Berg (1966, 1966a, 1966b), Walker (1963), Luitingh (1962), Callow (1961, 1962) and Elsley _et al_. (1964). The dissection technique was used by these workers as a tool in studying relative growth and development of tissues and to provide a sound biological and statistical approach to the appraisal of carcass composition and carcass merit.

B. Precautions Required During Dissection

The following considerations are necessary to minimize the risk of incorporation of error into the data. They were compiled from Butterfield and May (1965), Walker (1961) and from the experience of the author.

(i) There should be high humidity and low temperature in the room where dissection is done. In addition, damp cloths should be be used on the carcass and the dissected tissues during the entire procedure until final weights of tissues are recorded. This will prevent the loss of moisture from the tissues which is a very common source of error.

(ii) An exact knowledge of muscle attachments and relations is necessary to ensure accurate dissection.

(iii) Unnecessary handling of tissues should be minimized or it will amount to considerable loss of moisture from the tissue.

(iv) Muscles should be trimmed with caution following the basic principle that muscle contains fat but fat contains no lean tissue.

(v) It is essential that the same order of removal and general dissection procedure be followed throughout an experiment if comparable results are to be obtained.

C. Advantages and Disadvantages

1. Advantages

The total anatomical dissection technique has certain advantages over other separation techniques. These have become evident from the various studies resulting from the use of these techniques by Butterfield and various coworkers previously cited. Some of the advantages are enumerated below.

(i) The technique is simple and does not require any sophisticated or costly apparatus.

(ii) It is precise and anatomically definable which allows various workers to relate their findings to those of others using the same technique. Butcher's cuts and separations are not often nearly as precise.

(iii) Data obtained on individual components (e.g. muscles) can be used to study relative growth of the individual components and can be grouped to study relative growth of larger anatomical entities.

(iv) It provides a precise and direct endpoint for assessing gross carcass composition from experiments with various treatments be they nutritional, genetical, physiological or environmental in origin.

2. Disadvantages

There are also certain disadvantages of the total anatomical dissection technique.

(i) It is a very laborious and time consuming technique.

(ii) It requires a good knowledge of anatomy.

(iii) It permits only one measurement per animal.

(iv) It perhaps does not go far enough unless chemical analysis of the anatomical entities are included.

D. Bilateral Symmetry of the Carcass

The validity of assumming that data collected from one side of an animal carcass are representative of the entire carcass may be a subject of question. To clarify whether there are appreciable differences attributable to bilateral asymmetry or whether apparent differences arise mainly from errors in cutting, Butler *et al.* (1956) made 22 measurements on both sides of 77 beef carcasses. They did not find any significant difference in total lean and bone content in the 9-10-11th rib cut. Except for the slightly heavier mean weight of the left hindquarter and the left kidney knob caused by leaving the hanging tender (diaphragm) attached to the left side, little difference in mean weight was recorded. Their observations indicated a real variation in technique of splitting the carcass into two halves instead of a real difference in muscular development. Similar comparisons were made by Brungardt and Bray (1963). Of 26 measurements recorded from the two sides of 35 beef carcasses only kidney fat and pelvic fat, side weight (left sides being heavier with the diaphragm) and body wall thickness were found to vary significantly between sides. Proportion of muscle, bone and fat from the 9-10-11th rib cut did not differ significantly between the left and the right sides. The lower values (8%) from the left side for yield of trimmed wholesale cuts, retail and percent trimmed round were not significantly different from the corresponding values of the right side. Lasley and Kline (1957),

studying right and left sides of 222 pork carcasses, reported that errors in splitting the carcass may contribute to differences in wholesale cut weights, but expressed the opinion that such differences were not reflection of bilateral asymmetry. Carpenter *et al.* (1961) found that the fat content at three anatomical locations of the right and left longissimus from 35 medium or heavy pork carcasses to be similar. Breidenstein *et al.* (1964) recorded the weights of 9 major muscles from both sides of 20 pigs from 3 breeds representing equally two sexes and two market weight groups. They did not record any bilateral asymmetry between sides.

II. Mechanism of Sex Influence on the Growth of Tissues

It has been well established that entire males grow faster than entire females. There is a paucity of information on the mechanism which causes differences in the growth patterns of tissues among sexes. However, at an adequate level of nutrition, the influence of sex on the growth of muscle, bone and fat in an animal is two-fold. First, there is a direct effect of sex on growth resulting presumably from the genetic differences between males and females, and secondly, there is an indirect effect on sex due to the influences of hormones.

The basic genetic difference between males and females is in the sex chromosomes; all the autosomes being practically the same in both sexes. In almost all mammals the XX individuals are females and XY individuals are males. That the Y chromosome is necessary for male fertility was shown by Bridges (1916) and Stern and Hadorn (1936). Shen (1932) showed that gametic maturation ceased in male individuals having no Y chromosome. In most mammals, Y is genetically functional and essential for the development of testes (Pantelouris, 1967). However, in females one X chromosome started hyperfunctioning in early embryonic

life and inactivated the other X chromosome either by competitive inhibition or by a feedback mechanism (Lyon, 1962). This could be further supported by the fact that XO individuals were normal, fertile females (Welshons and Russel, 1959). In essence, the males had one fully functioning X chromosome and one genetically active Y chromosome whereas the females had only one dose of functioning X chromosome. The Y chromosome, therefore, may act as a trigger to impart the extra growth in males regulating metabolism through hormonal influences.

The growth of mammals is known to be regulated by the function of several endocrine glands. The hormones that impart characteristic differences in the development of tissues among sexes are (i) thyroxine from the thyroid (ii) estrogen from the ovary (iii) testosterone from the testes and (iv) growth hormone of the anterior pituitary.

The thyroid gland plays only a permissive role in the growth process. This assumption is based on the fact that all events involving cellular multiplication and growth occur at their optimal rates only in euthyroid individuals. Some growth was possible in thyroidectomised animals but none in the hypophysectomised animals (Evans _et al._, 1948; Simpson _et al._, 1950). Conversely, optimal growth was impossible in the thyroidectomised animal even with an intact pituitary gland or in hypothyroid animals injected with exogenous growth hormone (Eartly, 1954; Nalbandov, 1963). Further evidence came from several other studies that have been carried out on hypophysectomised animals and hypophysectomised-thyroidectomised animals with replacement of the missing hormones by thyroxine and growth hormone. Scow (1959) carried out carcass analysis on hypophysectomised-thyroidectomised rats given replacement therapy with growth hormone and/or thyroxine. He concluded that thyroidectomy also interrupted growth, but internal secretions of the thyroid could not substitute for growth hormone.

The recent studies of Goodall and Gavin (1966) and De Groot (1963) indicated that under conditions of adequate thyroxine administration in hypophysectomised rats, the rate of growth was dependent on the dosage of growth hormone. It is clear from these studies that both thyroxine and growth hormone are essential for optimal growth but that under adequate levels of thyroxine growth is dependent on the quantity of growth hormone.

The estrogens, apart from stimulation of the organs specific to the female, promote protein accretion in animals. So exogenous estrogen in the form of stilbestrol and hexoestrol has been widely used in animal production to promote growth, particularly in castrated males. Many reports have shown that estrogens promoted an increase in the early developing tissues in ruminants and pigs (Andrews et al., 1956; Beeson et al., 1956; Burroughs et al., 1955; Cahill et al., 1956; Berg et al., 1963; Clegg and Carroll, 1957; Clegg and Cole, 1954; Deans, et al., 1956; Kastelic et al., 1956; Ogilvie et al., 1960; Wilkinson et al., 1955, 1955a; Preston and Burrough, 1958; Perry et al., 1955; Preston and Gee, 1957; Struempler and Burroughs, 1959). The effects produced by the use of estrogenic hormones were an increase in growth rate and feed efficiency while at the same time there was an increase in nitrogen and water content of the carcass with a concurrent decrease in the fat content. The over all effect was to confer a more juvenile appearance in the carcass. This supports the contention that these steroids may be protein anabolic agents to a limited degree (Kochakian, 1946).

Everitt and Jury (1966a, b) in a detailed experiment on the effect of gonadectomy on growth and development showed, however, that ovariectomy reduced growth rate and led to an early maturation of the carcass.

It has not been conclusively explained, however, whether this was a direct influence or whether it was manifested through increased growth hormone secretion or through the pituitary-adrenal axis (Clegg and Cole, 1954). Struemplar and Burroughs (1959) showed in cattle and in sheep that the pituitary gland was bigger and that total growth hormone content was greater in stilbestrol treated animals compared to untreated controls. Slebodzinski (1962) claimed that increased production of growth hormone is the primary effect of stilbestrol. However, recent work has shown that estrogen may have a similar effect on protein metabolism to that of androgens or other developmental hormones. Estradiol treatment produced a rapid acceleration of synthetic reactions in the rat uterus which led to an accumulation of phospholipids, ribonucleic acid (RNA) and protein (Aizawa and Mueller, 1961; Noteboom and Gorski, 1963; Talwar and Segal, 1963; Ui and Mueller, 1963). The latter suggested that estrogen stimulated an initial step in the synthesis of RNA with the subsequent stimulation of overall protein metabolism. Whether this reaction of the uterus to estrogen is unique or whether it holds true for the tissues of the body as a whole has yet to be answered.

Nitrogen balance studies have established the protein anabolic action of androgen in animals. This effect was also accompanied by increased mobilisation of stored fat in the body. (Kochakian 1935, 1946, 1949, 1950a, 1964; Kochakian and Murlin, 1935; Kochakian and Stettner, 1948). The increase in weight of animals produced by protein accretion due to androgens did not change the composition of muscles (Kochakian 1966). Moreover, the anabolic action on protein is not mediated through any of the endocrine organs (Kochakian, 1950, 1964). Androgens induced the synthesis of protein by the regulation of RNA (Kochakian _et al_., 1961) and protein biosynthesis at the microsomal level (Breuer and Florini, 1965).

Growth hormone has also a protein anabolic effect in animals (Kochakian, 1950b). The principal immediate effects of growth hormone on nitrogen metabolism were:

(i) a fall in plasma amino acids (Russel, 1955),

(ii) increased tissue uptake of amino acids in vivo (Riggs and Walker, 1960), and in vitro (Noall et al., 1957),

and (iii) increased incorporation of amino acids into protein of rat diaphragm in vitro (Kostyo, 1964).

Again, the main effects of growth hormone upon fat and carbohydrate metabolism were:

(i) a rise in plasma non-esterified fatty acids (Raben and Hollenberg, 1959),

(ii) stimulation of lipolysis in isolated fat cells (Fain et al., 1965; Norbert, 1965),

(iii) increased uptake of non-esterified fatty acids by muscle followed by increased non-esterified fatty acids release by adipose tissue (Rabinowitz et al., 1965),

and (iv) stimulation of the long chain fatty acid utilization in the epididymal fat pads. This has been shown through augmentation of the oxidation of palmitate-1-^{14}C to $^{14}CO_2$ and its increased incorporation into phospholipids and triglycerides. There was also an increased long chain acyl CoA-carnitine acyltransferase activity in the fat pad of treated animals and increased incorporation of phosphorus into phospholipids, (Goldman, 1967).

In addition growth hormone acts in a synergistic way with androgen in all tissues so far as protein anabolism is concerned (Kochakian and Stettner, 1948) but this summation effect on fat catabolism was not found by Kochakian (1966). The increase in body weight through the actions of androgen and growth hormone was not only due to a progressive accretion

of protein accompanying water but also to a simultaneous decrease in body fat. Growth hormone appeared to be more effective than androgen in the utilization of body fat. The induced protein synthesis primarily occurred in the carcasses (Kochakian and Stettner, 1948). Baird _et_ _al_., (1952) indicated why the rate of growth of rapidly growing animals declines as they reach maturity. They determined the relation between the amount of growth hormone in the pituitary gland and body weight. As body weight increased, anterior pituitary size increased but at a proportionately slower rate, while growth hormone per unit of pituitary weight remained essentially the same. Thus as the animals approached maturity there was less growth hormone available per unit of body weight. In fact the availability of growth hormone per unit tissue began to decline before the growth curve of the animal went into its rapid phase. This indicates that, because the rapid growth phase mostly comprises muscle development, growth hormone goes further per unit of muscle than per unit of bone. The characteristic effect of growth hormone on nitrogen retention is in line with this observation. Although this work (Nalbandov, 1963) was carried out in pigs, it seems likely that same general principle applies to ruminants (Lamond, 1963) as the growth hormone of the pig and the cow belong to same immunochemical group. The hypothesis that availability of growth hormone per unit of tissue is a basic determinant of growth (Nalbandov, 1963) has important practical consequences. It is possible that selection for rapid rate of growth is, in fact, selection for greater availability of growth hormone.

These studies are very nicely supported by Simpson _et_ _al_. (1950) who proposed a "dilution" theory of growth stasis. He found that when 0.4 mg. per day of somatotrophin was injected into rats, they grew for

only 23 days and they plateaued. At this point the amount injected had to be increased to 0.6 mg. in order to cause further growth which, however, again culminated in growth stasis. When the doses were raised successively to 1.0, then 1.5 and eventually to 2.0 mg. per day, further growth responses were elicited by each increase in dose, but each increase in dose culminated eventually in a growth plateau. After the last course of treatment the rats weighed 440-530 gms. This experiment lends to support to the contention that vigorous growth can occur only so long as the ratio of circulating somatotrophin to unit of body tissue is sufficiently high to stimulate protein synthesis abundant enough to cause bone and muscle growth. When available hormone becomes too "diluted", the animal can maintain its gains and do repair jobs but it is incapable of actual true growth. Moreover, recent experiments (Birge _et_ _al_., 1967; Jones _et_ _al_., 1965) have also indicated that males have more growth hormone than the females and this difference increased in the post-weaning stages of life. This higher amount of growth hormone in males compared to females along with testosterone is probably responsible for the extra growth in males.

III. Energy Metabolism in Young Growing Animals

The quantity and the quality of food are important factors influencing the rate and composition of gain in animals. Food supplied to animals ultimately acts as an energy-yielding substrate to perform new synthesis or deposition of tissues according to the physiological demands of the animals. The energy given by the different nutrients varies with the chemical nature of the substrate which supplies the energy for new synthesis. Similarly, the calorific value of the increments in the weight of the body of an animal during its growth depends on its physiological age and the biological value of the food. The calorific value for increase in unit live weight in animals increases with age because the juvenile growth contains more water, protein and minerals and less fat than does later growth. This can be explained from the estimates of energy cost of unit weight of protein synthesis and fat deposition in animals. The energy cost of unit weight protein synthesis is about one-half the cost of a unit weight of fat deposition in young growing animals. The energy cost of protein deposition in growing lambs (Kielanowski and Lassota, 1960; Kielanowski, 1965) and baby pigs (Schiemann _et_ _al_., 1962), expressed in kcal of metabolizable energy per 1 gram of protein synthesised was estimated to be 7.07 and 7.51 respectively. These estimates do not exceed very much the theoretical values predicted by Blaxter (1962) and by Schiemann (1963) of 6.2-6.4 kcal of metabolizable energy per 1 gram of protein. In addition, the difference found in the efficiency of protein deposition between the species investigated was not great and appeared to indicate that energy cost of protein synthesis was between 7 and 8 kcal of metabolizable energy per 1 gram of protein synthesis in all mammals (Kielanowski, 1965). On the other hand, the estimated cost of fat deposition per 1 gram of fat was found to be 14.97 kcal metabolizable

energy in both young growing lambs and adult sheep (Kielanowski and Lassota, 1960). Hoffmann et al. (1962) and Crasemann (1954) estimated the energy cost of fat deposition to be 15.93 and 13.94 kcal of metabolizable energy per 1 gram of fat stored in the body of adult sheep. These findings seem to indicate that fat deposition in a suckling lamb, in spite of the absence of normal rumen function, follows the same pattern as in an adult sheep. These results reveal why the energy retained per unit of gain increases as the animal matures.

The biological value of the protein is another important factor in the efficiency of energy utilization of growing animals. The efficient utilization of total nitrogen ingested depends not only on its quantity but also the quality of protein given to the animals. If the level of essential amino acids in a particular protein deviates grossly from that of the physiological requirements of the animal then the biological scoring of the protein will tend to be at a low ebb. Several reports have been published with a view to evaluate the physiological requirement of protein for different species of domestic animals (Balch and Rowland, 1959; Ritzman and Colovos, 1943; Kropf et al., 1959).

The expenditure of energy available to the animal appears to be divisible into three main groups (Blaxter, 1967):

(i) Inevitable and primary expenditures which are always met either from energy released in the oxidation of food or from the oxidation of body reserves. These include all forms of work which the body performs, whether the work of maintenance, muscular work, or the work of thermoregulation.

(ii) Syntheses which are usually performed when food in excess of that required to meet primary expenditures is the energy-

yielding substrate, but which can occur to some extent at the expense of body reserves. This includes the growth of protein mass of the body. This process is sensitive to a greater or lesser extent to the overall turnover of the energy by the animal, and it appears to have maximal rates characteristic of the individual, beyond which increase in energy input results in no further synthesis.

(iii) Deposition of body fat which can occur only when food is supplied in excess of needs for primary expenditures. Whether fat is deposited, and in what quantities, when energy in excess of primary expenditures is supplied depends on the precise relationship between rates of synthesis of protein and the excess energy supplied.

A number of experiments have inferred a limit in the capacity of the animal to synthesize new protein in young growing animals. Similarly another question arises as to the limits in the capacity of the animal to synthesize fat or to expend energy. There is ample evidence that there is a limit to the daily rate or protein synthesis of body protein in growth. It is well illustrated by the experiment of Clausen and Ludwigsen (1961) with pigs. They showed that with increase in feeding level, the proportion of meat in the carcass fell and the amount of fat increased. Clausen and Ludwigsen (1957, 1961), in drawing conclusions from a wide series of experiments with pigs, stated that "when the daily requirements for maintenance and meat production have been covered, the rest of the daily feed intake will be utilized for fat production; that is the higher the daily intake of energy the fatter the pig". They also concluded that the limitation of converting dietary nitrogen to body protein is under

genetic control and could be improved by selection. This, while generally true, should not be misinterpreted. There is no sharp demarcation of a food intake optimal for growth beyond which fattening occurs. The absence of any demarcation of rates of protein synthesis beyond which additional food is converted to fat was well illustrated by Blaxter (1952, 1967) who showed with increasing food intake protein synthesis increased at an ever-diminishing rate, whereas fat deposition increased at an ever-increasing rate. So the capacity to synthesize fat from the absorbed nutrients does not appear to diminish in the attainable range of food intakes in adult ruminants. These animals, mature in size, which carry out but small synthesis of protein-containing materials in the form of hair growth and renewal of surface cells, when food given in excess of current expenditure, store it almost entirely as fat. Wierzuchowski and Ling (1925) fed pigs 3 times the amount of food necessary to maintain weight and found no decline in the efficiency of conversion of absorbed food to body fat. The rate of fat deposition was found to be 12 mg/kg of pig/min. Such a very high rate of synthesis has not been observed in ruminants but there is no reason to believe that the capacity of ruminants to produce fat is ever exceeded. This discussion appears to explain the ways in which the food is used to meet energy expenditure and synthesis of protein or deposition of fat. The ways in which food determines productive functions is more complicated problem and probably is yet to be answered.

IV. The Importance of the Relationships Involving Muscle, Bone and Fat

Berg and Butterfield (1968) stated that "the quantitative requirements in the carcass are best met when muscle is maximum, bone is minimum and fat is at an optimum determined by local consumer preferences". Hankins *et al.* (1943) also expressed the same view for the most desirable carcass.

To do this, an objective yardstick is needed which would most reliably estimate carcass composition. Choice of endpoint such as a constant live weight or constant age may influence differences in carcass composition and obscure the effect, if any of the experimental treatments on relative tissue growth. Evaluation of performance in beef cattle by the aforesaid systems is not legitimate as the growth patterns of major tissues in the carcass are influenced by physiological maturity which in turn is influenced by breed, sex and nutrition. As a result carcasses at a given age or at a constant live weight vary in proportions of tissues (Berg and Butterfield, 1968).

The ideal index of the carcass merit would be one which could either be independent of the environmental effects such as weight or age or one in which adjustment for these effects would be simple and effective. Tulloh (1963) suggested an index of relative amount of muscle when adjusted for the empty body weights. Elsley _et_ _al_. (1964) recommended adjusting total muscle to a common fat-free tissue weight. They found that fat is a unique tissue which functions very different from those of other major tissues. They re-analysed the data of McMeekan (1940a, b, c) and Pálsson and Vergés (1952a, b) to show that greatest part of the difference in the growth patterns of pigs and sheep, imparted by the plane of nutrition, was due to the difference in the deposition of fat. These findings are congruent with those of Wallace (1948), Wilson (1954a), Tulloh (1963a) and Stuedemann _et_ _al_. (1968).

Similarly, Berg and Butterfield (1966) observed that adjustment by covariance to a constant total muscle plus bone was legitimate for comparison of total muscle and found significant breed differences in total muscle when the variation in muscle plus bone was removed. Muscle/bone ratio adjusted for carcass weight was suggested as an index for carcass

merit along with percent fat in the carcass also adjusted to a constant carcass or muscle plus bone weight. These indexes take into account the normal growth and relative growth of the tissues and their relationships and minimize effects of differences in weight at slaughter between treatment groups.

V. Measurement of Relative Growth and Estimation of Growth Coefficients

The growth process is generally considered from two aspects; firstly, the increase of body mass in time, usually described by the live weight growth curve for the whole animal, and secondly, the changes in the form of the animal resulting from differences in the relative growth rates of the component parts of the body (Fowler, 1967). Gross live weight changes are comparatively easily measured by expressing the live weight, carcass weight or tissue gain (muscle, bone or fat) per unit time (Brody, 1945). The average growth rate expressed in this way is not open to very great objection providing that the interval of time is short. If the time interval is long the average growth rate gives no idea of the growth rate at any particular time. The measurement and evaluation of body development is a more complex problem than the measurement of changes in total body weight because satisfactory data are obtained less easily. Ideally, studies of relative growth should be carried out by repeated measurement of variables or component tissues from the same animals. This is not feasible for anatomical entities which are measurable only at post-mortem dissection. Clearly for the most penetrating inquiry into this subject, data from animals which have been subjected to comprehensive anatomical dissection are required (Fowler, 1967).

To estimate the relations between components, organs and tissues which are rarely linear over wide ranges in body weight, especially when observ-

ations at or near birth are included, a simple mathematical approximation for describing the differential growth is required. The effort to find such simple relation between two growing dimensions has led generally to the use of an allometric equation (Huxley, 1924, 1932; Reeve and Huxley, 1945) of the form:

$$Y = ax^b$$

Where, Y = weight of an organ or part, x = weight of animal (or another appropriate independent variable) and "a" and "b" are the two constants. Huxley (1932) was the first to demonstrate experimentally the fixed nature of the relationships between body components during growth. He showed that within a species or genotype the weight of a particular tissue or organ was virtually determined by the total weight of the animal. In this equation "b" is seldom 1.0 and therefore the equation represents an exponential relation and is consistent with the arguments that morphogenic changes will be of a regular and fixed kind. There are several examples in the literature of the need for caution in applying this formula too extensively, for example Reeve and Huxley (1945). It should, therefore, be noted that although the allometric equation provides a valuable and simple mathematical approximation for describing differential growth, there are no intrinsic biological laws which make it apply exactly. This exponent "b" is the ratio of the two specific growth rates and is usually known as the growth coefficient. Being a ratio it is a pure number and is not constant, but may be so when specific growth rate changes in such a manner as not to affect their ratio. What is important is to know how nearly constant "b" is , and to what this constancy is due. The value of the allometric equations depends on this. If "b" is greater than 1, the organ or the dimension grows faster than the body or control dimension; if "b" is less than 1, it grows more slowly and if "b" is equal to 1, an organ exhibits

isometry and grows at the same rate as the body or the control dimension.

In the logarithmic form the equation becomes a straight line.

$$\log Y = \text{Log } A + b \log X$$

Being a straight line, it becomes an easy function to handle statistically and graphically, deviations from linearity from the double logarithmic plot could be seen easily (Tulloh, 1963). Berg and Butterfield (1966) in steers and Elsley et al. (1964) in sheep and pigs related muscle, bone and fat to total muscle plus bone through this double logarithmic scale. The "b" values indicated the proportionate growth of muscle, bone and fat to muscle plus bone and were referred to as growth coefficients (Table 1). The total weight of muscle plus bone in the carcass was chosen as the control dimension because (i) it was not subject to large dissection errors, (ii) it is the best substitute for fat-free body mass, (iii) it excludes viscera, the weight of which may be more subject to short term fluctuations. In addition, fat deposition is not closely related to the growth of fat-free mass but varies with the nutritional level (Lucas, et al., 1959; Elsley, 1963a, b) and with the sex of the animal (Berg and Butterfield, 1968). The inclusion of such a highly variable tissue will incorporate large error in the control dimension and will thwart any attempt to fit a precise equation to the data.

TABLE 1

Estimates of growth coefficients (b) from the relationship $\log_{10}Y = a + b \log_{10}X$, where X = (muscle + bone), based on dissection data from cattle, sheep and pigs

	Dependent Variables						
	Muscle		Bone		Fat		
(Y)	b	S.E. of b	b	S.E. of b	b	S.E. of b	Sources of data
Type of animal							
Cattle	1.05	0.01	0.82	0.03	1.78	0.20	Berg and Butterfield (1966)
Sheep	1.10	0.01	0.75	0.03	1.82 2.15	0.07[1] 0.13[2]	Elsley *et al.* (1964)
Pigs	1.04	0.01	0.81	0.02	1.49 1.29	0.11 0.10	Elsley *et al.* (1964)

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[1] Growth coefficient for intermuscular fat.

[2] Growth coefficient for subcutaneous fat.

EXPERIMENTAL

I. Objectives

The present research project in beef cattle of different genotypes and sexes has been directed towards three main objectives:

i) a study of factors influencing the growth patterns of muscle, bone and fatty tissue;

ii) a study of the relationships involving muscle, muscle/bone ratio, percent fat and cold carcass weight, with a view to developing an index for assessment of carcass composition;

and iii) an appraisal of the influence of breed and sex on growth allometry of muscle, bone and fatty tissues by estimation of growth coefficients.

II. Materials and Methods

A. Experimental Animals

1. Sources

One hundred and sixty-eight beef cattle of various genotypes representing 3 sexes and 4 different sources have been used in this study. Most of the animals were from the University of Alberta beef research herd at Kinsella. Eight Holstein bulls were from the dairy cattle research herd of the University of Alberta. Eight Jersey bull calves were obtained from the Canada Department of Agriculture Research Station, Lethbridge. These bulls were fed and raised with the University dairy herd on a specific nutritional experiment. Eleven steers and ten heifers of the Hereford breed came from Alberta Beef Cattle Performance Association (ABCPA) progeny test program at Bassano, Alberta. A complete list of the codes which will be used to indicate the different breed groups, sexes and sources are given in Appendix Table 1.

2. Description and general management of the animals

a) Beef cattle research herd of the University

The University of Alberta established the foundation for an extensive beef breeding research project in the fall of 1960 at Kinsella, 95 miles southeast of Edmonton, Alberta. The project has been outlined in general terms by Berg and McElroy (1968). Two distinct herds of cattle were established as the base for continuing breeding studies. One herd was established from a purebred Hereford (HE) foundation and the other was started by crossing among three breeds - Angus, Charolais and Galloway. The latter is referred to as the hybrid (HY) herd.

The animals from the Kinsella herd were mostly from the 1965 and 1966 calf crops with a few from the 1967 crop. They were born in April and

May, nursed on their mothers without creep feed until October when they were weaned. They were then transferred to a performance test ration of grain plus supplement self-fed. Cut hay free choice was fed to the 1965 groups. The ration fed to 1965 calf crop has been outlined in Appendix Table 2. In 1966 and 1967 hay feeding was limited to 0.9 kg per head per day. Concentrate was full fed and consisted of a grain mixture of rolled oats and barley in 1:3 ratio plus a pelleted supplement (Appendix Table 3) at a level of 5% of the grain mixture. The 1965 groups were slaughtered in 1966 at approximately 1000 lb (455 kg) live weight. But in 1967 and 1968 slaughter was over a wide range of live weight to facilitate the study of carcass composition at different stages of development.

b) Dairy cattle research herd of the University of Alberta

(i) Holstein Bulls

Eight purebred Holstein (HL) bull calves from the University dairy herd, were divided into 2 groups of 4 bulls to study the effects of rolled versus whole grain on digestibility of the ration. The animals were treated to a preliminary adjustment period of at least 4 weeks, wherein one group was fed rolled barley and the other group was fed whole barley. Thereafter, in four consecutive 8-week periods, group 1 was fed, alternatively, rolled barley, whole barley, rolled oats and whole oats. Group 2 8-week schedules were whole barley, rolled barley, whole oats and rolled oats (Appendix Table 4). In addition to the grain, the bulls were fed a pelleted supplement (Appendix Table 5) at a level of 7.5% of the ration to supply 2% of the ration as urea. Except when digestion studies were conducted, the bulls were self-fed, and water was available free choice. The pens were bedded with shavings to minimize consumption of roughage. Following the last digestion trial all the bulls were fed

rolled barley plus pelleted supplement until slaughter.

These bulls will be treated as a single group in the present investigation since there was very little difference between the 2 groups in average daily gain, average daily feed consumed or feed conversion (Grieve 1968). In addition, the design of the study and the ration changes would be expected to produce similar effects on the carcass composition of both groups.

(ii) Jersey Bulls

Eight purebred Jersey (JR) bull calves from the Canada Department of Agriculture Research Station, Lethbridge, were divided into 2 groups of 4 bulls each to study the differences between oats and barley in high grain rations on carcass composition. The average initial age of Group 1 and Group 2 (Table 5) was 148 and 146 days respectively. The average initial live weight of Group 1 and Group 2 was 87.5 and 85.8 kg respectively. When they were placed on test, Group 1 bull calves were fed rolled oats and Group 2 calves were fed rolled barley for 252 and 267 days respectively. Pelleted supplement (Appendix Table 5) was fed at a level of 7.5% of the ration to supply 2% of the ration as urea. The bulls were self-fed and had free access to water.

Differences in carcass composition did arise between the two groups of JR bulls and therefore their inclusion as a single breed group in the present study will be interpreted in light of these results.

c) The Alberta Beef Cattle Performance Association

ABCPA has been carrying out progeny tests for a number of years to evaluate the merit of sires available to ranchers through artificial insemination as well as some sires used in natural service. Representative groups of calves from selected sires were placed on feed as soon as possible after weaning to obtain preliminary information

on the sires before the next breeding season.

The feeding program was designed to correspond to commercial feedlot practices where the animals are full-fed on a complete mixed finishing ration of concentrate and chopped hay.

Selected groups of steers and heifers from the 1966-67 test were available for appraisal of carcass composition. Five Hereford sire groups were represented by both steer and heifer progeny in this test.

B. Total Dissection Technique

The total dissection technique described by Butterfield (1963) , and in more detail by Butterfield and May (1965) was used. Briefly it involved the quantitative separation of one half of the carcass into individual muscles, bones and fatty tissues. The principle followed was that fat and other tissues contain no muscle but muscle contains some other tissue. Therefore severance of muscle from tendon was made at the level of the last vestige of muscle. Fatty tissue was weighed in three categories, subcutaneous, intermuscular and internal (body cavity) fat. Loose connective tissue was weighed with fat. Tendons were weighed separately. Certain muscles were not weighed and became scrap e.g., muscles of the tail (sacrococcygeus dorsalis, lateralis and ventralis) and diaphragm (tendinous center along with muscular costal and sternal parts).

C. Statistical Analyses

The weights of individual muscles, bones and three different categories of fat were recorded in grams. All other measurements of weights were taken in pounds and converted to grams.

The APL system in the IBM 360/67 computer through an IBM 2741 terminal was extensively used to calculate analyses of variance and covariance, simple linear regressions and correlations. The

principles of computational procedures were adapted from Steel and Torrie (1960), Snedecor (1956) and Winer (1962).

III. Results and Discussions

A. Factors Influencing Total and Proportion of Muscle, Bone and Fatty Tissue

1. Variations in total and proportion of muscle, bone and fat among diverse breed groups

Age and live weights at slaughter along with means and standard deviations of cold carcass weights, total and proportion of muscle, bone, fat and muscle/bone ratios from diverse genetic groups of bulls, steers and heifers are shown in Tables 2, 3 and 4 respectively.

Total tissue weights differed significantly ($P < 0.01$) among various breed groups of bulls (Table 2), steers (Table 3) but showed no significant difference between two breeds of heifers (Table 4). These data appeared to indicate that different breed groups of steers and bulls followed significantly different patterns of development in terms of muscle, bone and fat reflecting genetic influences on carcass composition in the process of tissue growth. These results are in good agreement with those found by Berg and Butterfield (1966, 1968), in different breeds of steers and bulls. On the contrary, muscle, bone and fat development tended to show a quite similar pattern in two breed groups of heifers in the present study which might be expected since they were not as diverse in breed type as the bulls and steers.

Breed groups of bulls and steers differed significantly ($P < 0.01$) in the proportion of muscle, bone and fat. However, proportion of these tissues did not reach a level of significant difference between two breeds of heifers. This would mean that breed groups of steers and bulls were at different stages of physiological development, which was not

TABLE 2

Cold carcass weights, live weights and age at slaughter with means, standard deviations and percentages of muscle, bone and fat and muscle/bone ratio from dissection of half carcasses from fifty-nine bulls

Group	Cold Carcass Wt. kg.	Age (days)	Live Weight kg.	Muscle		Bone		Fat		Muscle/Bone Ratio
				kg.	%	kg.	%	kg.	%	
1. HY	145.4	443	496.5	95.7	66.4	17.3	12.1	30.2	21.0	5.5
(17)[1]	±24.3			±18.1	±4.1	±2.2	±1.0	± 7.6	±4.1	±0.6
2. HY(C.A.G.) x HE	135.9	388	470.3	80.9	60.6	16.9	12.7	35.9	26.1	4.8
(5)	±23.9			±10.5	±4.1	±1.8	±1.1	±12.8	±4.8	±0.4
3. HE	135.3	461	466.2	80.4	60.6	15.3	11.9	37.4	27.3	5.3
(13)	±21.3			± 9.6	±4.4	±1.6	±1.2	±12.3	±5.3	±0.4
4. HL	111.1	386	416.0	75.9	69.2	18.3	16.7	14.9	13.5	4.2
(8)	± 7.5			± 4.4	±1.1	±1.4	±0.8	± 2.2	±1.4	±0.2
5. SH Cross	89.0	317	322.3	57.6	65.5	11.9	13.7	17.7	19.9	4.8
(8)	±18.6			±12.1	±2.2	±2.0	±1.3	± 5.1	±2.1	±0.5
6. JR	73.0	407	294.0	47.0	65.3	10.7	14.9	14.0	19.2	4.4
(8)	± 8.0			± 5.0	±4.0	±0.7	±1.1	± 4.7	±4.9	±0.2
Variance ratio for group means[2]	21.5**			21.4**	7.7**	26.3**	30.1**	14.5**	13.1**	14.9**

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[1] Numbers in parentheses indicate number of animals.

[2] 5 and 53 degrees of freedom.

** Significant at $P < 0.01$.

TABLE 3

Cold carcass weights, live weights and age at slaughter with means, standard deviations and percentages of muscle, bone and fat and muscle/bone ratio from dissection of half carcasses from ninety-one steers

Group	Cold Carcass wt. kg.	Age (days)	Live Weight kg.	Muscle		Bone		Fat		Muscle/Bone Ratio
				kg.	%	kg.	%	kg.	%	
1. BS Cross (14)[1]	126.0 ±16.7	404	456.8	75.8 ±10.1	60.8 ±2.8	17.2 ±2.0	13.9 ±1.0	30.9 ± 6.8	24.6 ±3.3	4.4 ±0.3
2. HY (C.A.G.) x HE (16)	131.7 ±11.6	434	461.8	74.1 ± 7.9	56.8 ±4.9	15.5 ±1.5	11.9 ±0.9	40.4 ± 9.1	30.8 ±5.7	4.8 ±0.2
3. HY (16)	133.4 ±17.6	433	461.5	73.6 ± 8.1	56.1 ±4.1	15.7 ±1.9	12.0 ±1.5	42.0 ±11.2	31.4 ±5.3	4.7 ±0.4
4. HL (5)	120.1 ± 6.3	464	439.5	70.8 ± 2.6	59.9 ±2.3	17.6 ±0.6	14.9 ±0.6	29.3 ± 4.8	24.6 ±2.7	4.0 ±0.2
5. HE x HY (C.A.G.) (8)	120.2 ±11.2	441	433.6	72.5 ± 5.7	60.7 ±2.5	15.5 ±1.7	13.0 ±1.5	31.1 ± 6.4	25.8 ±3.9	4.7 ±0.4
6. HE x HY (A.G.) (13)	124.5 ±10.9	425	436.2	70.2 ± 4.9	57.1 ±3.9	14.4 ±0.7	12.0 ±1.2	38.4 ± 8.7	30.7 ±4.9	4.9 ±0.3
7. HE (11)	107.4 ±10.5	402	373.9	61.7 ± 4.1	58.1 ±4.0	12.7 ±1.0	11.8 ±1.0	31.8 ± 7.9	29.5 ±4.8	4.9 ±0.2
8. SH Cross (8)	87.1 ±16.3	326	310.4	52.9 ± 9.8	59.2 ±1.5	11.2 ±1.8	13.1 ±0.6	23.5 ± 5.1	27.1 ±1.7	4.7 ±0.2
Variance ratio for group means[2]	12.1**			12.0**	3.0**	17.6**	8.8**	6.4**	4.5**	7.1**

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[1] Numbers in parentheses indicate number of animals.

[2] 7 and 83 degrees of freedom.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

TABLE 4

Cold carcass weights, live weights, and age at slaughter with means, standard deviations and percentages of muscle, bone and fat and muscle/bone ratio from dissection of half carcasses from eighteen heifers

Group	Cold Carcass wt. kg.	Age (days)	Live Weight kg.	Muscle		Bone		Fat		Muscle/Bone Ratio
				kg.	%	kg.	%	kg.	%	
1. HE (10)[1]	85.7 ± 6.6	365	305.5	48.2 ±5.3	57.6 ±2.3	10.1 ±1.1	11.6 ±0.6	25.9 ±1.8	30.4 ±2.3	4.8 ±0.3
2. SH cross (8)	75.6 ±13.9	353	276.9	44.0 ±6.7	59.1 ±2.6	9.5 ±0.6	12.6 ±1.9	20.9 ±7.4	27.4 ±4.4	4.6 ±0.7
Variance ratio for group means[2]	4.13			3.4	2.1	4.1	1.7	4.3	3.6	0.3

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[1] Numbers in parentheses indicate number of animals.

[2] 1 and 16 degrees of freedom.

surprising considering their diverse genotypes, weight and age differences.

The two groups of heifers on the other hand were in the same physiological stage of development and appeared to follow a similar trend in growth pattern of tissues.

Muscle/bone ratios differed significantly ($P < 0.01$) among breed groups of bulls and steers but did not reach a level of significant difference between two breeds of heifers. This appeared to indicate that pattern of muscle and bone development is reflected by muscle/bone ratio in the carcass.

There was large within group variation in cold carcass weights, total and proportion of muscle and fat in three sexes as indicated by large standard deviations. This could obviously be related to their diverse genetic backgrounds and live weights resulting in different stages of physiological development. However, within group variation in total and proportion of bone and muscle/bone ratio was comparatively small which was reflected by low standard deviations. Bone growth being slower but steadier showed less variation than muscle and fat which reflected stage of development and external influences more markedly in agreement with Hammond (1944), Yeates (1964) and Butterfield (1965b).

2. Influences of sex on total and proportion of muscle, bone and fat

Sex is known to have marked influence on the onset of fattening with heifers fattening at lighter weights than steers, and steers at lighter weights than bulls (Berg and Butterfield, 1968). In the present study, pooling all animals, it was found that bulls and steers had similar cold carcass weights with heifers being comparatively lighter (Table 5). It was expected that older and heavier animals would yield greater cold carcass weights but bulls contained a significantly ($P < 0.01$)

TABLE 5

Cold carcass weight, age and live weight at slaughter with means and standard deviations and percentages of muscle, bone and fat and muscle/bone ratio from dissection of half carcasses from ninety-one steers, fifty-nine bulls and eighteen heifers

Group	Cold Carcass wt. kg.	Age (days)	Live Weight kg.	Muscle		Bone		Fat		Muscle/Bone Ratio
				kg.	%	kg.	%	kg.	%	
1. Steers	121.6	417	422.07	69.8	58.3	15.0	12.6	35.0	28.7	4.9
(91)[1]	±18.7			±10.1	±4.0	±2.3	±1.4	± 9.9	±5.1	±0.4
2. Bulls	120.3	413	410.885	76.6	64.7	15.3	13.3	26.3	21.4	5.0
(59)	±32.3			±20.4	±4.6	±3.1	±2.0	±12.3	±5.9	±0.7
3. Heifers	81.2	359	291.2	46.9	58.2	9.7	12.2	23.6	29.1	4.7
(18)	±11.0			± 6.2	±2.5	±1.0	±1.3	± 5.4	±3.5	±0.5
Variance ratio for group means[2]	22.1**			29.2**	48.6**	36.6**	4.3*	16.7**	36.9**	7.3**

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[1] Numbers in parentheses indicate number of animals.

[2] 2 and 165 degrees of freedom

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

TABLE 6

Among sex group test of significant differences for total and percentages of muscle, bone and fat, cold carcass weight and muscle/bone ratio

Breed	HE				SH Cross				HY			HY (C.A.G.) x HE		
Sex Group	Bulls	Steers	Heifers	Sig. Level	Bulls	Steers	Heifers	Sig. Level	Bulls	Steers	Sig. Level	Bulls	Steers	Sig. Level
Number of Animals	13	11	10		8	8	8		17	16		5	16	
Age (days)	461	402	365		317	326	353		443	433		388	434	
Live Weight (kg.)	466.2	373.9	305.5		322.3	310.4	276.9		496.5	461.5		470.3	461.8	
Gain/Day (kg.)	1.01	0.93	0.84		1.02	0.95	0.78		1.12	1.07		1.21	1.06	
1. Cold Carcass wt. (kg.)	135.3	107.4	85.6	**	89.0	87.1	75.6	--	145.4	133.4	--	135.9	131.7	--
2. Muscle (kg.)	80.4	61.7	48.2	**	57.6	52.9	44.0	*	95.7	73.6	**	80.9	74.1	--
3. Bone (kg.)	15.3	12.7	10.1	**	11.9	11.2	9.5	**	17.3	15.7	*	16.9	15.5	--
4. Fat (kg.)	37.4	31.8	25.4	*	17.7	23.5	20.9	--	30.2	42.0	**	35.9	40.4	--
5. Percent Muscle	60.6	58.1	57.6	--	65.5	59.2	59.1	**	66.4	56.1	**	60.6	56.8	--
6. Percent Bone	11.9	11.8	11.6	--	13.7	13.1	12.6	--	12.1	12.0	--	12.7	11.9	--
7. Percent Fat	27.3	29.5	30.4	--	19.9	27.1	27.4	**	21.0	31.4	**	26.1	30.8	--
8. Muscle/Bone Ratio	5.3	4.9	4.8	**	4.8	4.7	4.6	--	5.5	4.7	**	4.8	4.8	--

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

greater amount of muscle and bone and a lesser amount of dissectable fat than steers. This would mean that steers fattened at lighter weights than bulls. Again, relative to live weight and cold carcass weight heifers contained lesser amounts of lean and bone with a greater amount of fat in the carcass. This seemed to indicate, though not quite precisely, that heifers fattened much earlier compared to bulls and steers.

However, on a proportionate basis bulls contained significantly ($P < 0.01$ or $P < 0.05$) greater percentages of muscle and bone which, in turn, were followed by steers and heifers. Heifers even at considerably lighter live weight had a significantly ($P < 0.01$) greater proportion of fat over steers and steers over bulls. This would clearly mean that sexes differed in weight at the onset of fattening phase. Bulls tended to show slightly higher muscle/bone ratios than steers which were superior to heifers.

Sex differences were also appraised within breed groups. HE bulls had a significantly ($P < 0.01$ or $P < 0.05$) higher cold carcass weight and total muscle, bone and fat which were followed by steers and heifers respectively (Table 6). The proportion of tissues did not differ significantly among the 3 sexes which suggests that they were at similar stages of development even though at differing weights. Alternatively and perhaps more sensibly, it would mean that HE bulls showed prolonged growth impetus for muscle and bone and delayed onset of fattening as compared to steers which in turn showed a similar relationship to heifers in agreement with Berg and Butterfield (1968). Consequently, HE bulls had significantly ($P < 0.01$) higher muscle/bone ratios over steers and steers over heifers.

In the Shorthorn (SH) cross groups, bulls and steers had similar carcass weights but the heifers had lighter carcasses. This resulted

in differing composition between bulls and steers but not between steers and heifers indicating that the bulls were at a different stage of development than the steers and heifers. Bull carcasses had a higher percentage of muscle and a lower percentage of fat while percentage of bone differences did not reach a level of significance. The muscle/bone ratio did not differ significantly between the sexes but again it was higher for bulls over steers and steers over heifers.

In the comparison of hybrid (HY) bulls and steers the bulls were heavier at slaughter. Nevertheless the carcasses from steers were much fatter containing a higher total amount and percentage of fat. The bull carcasses had a higher percentage of muscle but differences in percentage of bone between bulls and steers were slight and non-significant. This particular breed group, contained a higher proportion of Charolais than other groups in Table 6 and showed a tendency to late fattening. This was particularly evident in the bulls which showed a prolonged muscle growth impetus and reached the highest muscle/bone ratios in the present study being quite superior in this regard to the comparable steers.

Hybrid X Hereford (HY (C.A.G) X HE) bulls and steers were slaughtered at similar live weights and although no significant differences were detected in body composition the trend was similar to other breed groups with bulls having a higher percentage of muscle and a lower percentage of fat than steers. However muscle/bone ratio did not favor bulls in this breed group.

In general when sexes are being compared with respect to carcass composition, it is clear that weight must be taken into consideration. Bulls seem to have a prolonged impetus for muscle growth and a tendency to fatten at heavier weights than steers, and steers bear a similar

relationship to heifers. At equal weights heifers would be fatter than steers and steers fatter than bulls. However at equal percentages of fat in the carcass all 3 sexes could be very similar in carcass composition although quite different in carcass weights.

The present study alone does not provide all the precise information about the influence of sex on the growth patterns and relative growth of tissues due to the scarcity of information at various stages of development. However, Bradley _et al_. (1966) compared 34 steer and 34 heifer carcasses at carcass weights of 298 and 267 kg, respectively. The fat percentages estimated from the 9-11th rib-cut were 40.7 and 44.6 and muscle/bone ratios were 3.31 and 3.19, respectively.

Breidenstein, _et al_. (1963) compared 78 sides of steers with 93 sides of heifers. The side weights were similar for the sexes but heifers had a greater amount of waste indicating greater fatness. Prescott and Lamming (1964) compared steers castrated at seven months with bulls. The cold carcass weights were 218 and 229 kg for steers and bulls. The steers had 29.2% fat in the 10th rib-cut compared to 16.8% for the bulls and the steers were inferior in muscle/bone ratio of the same cut at 2.72 vs. 3.38 for bulls. Bailey _et al_. (1966) found similar results with steers and bulls at 254 and 259 kg carcass weight, respectively. The composition of 9-11th rib was 40.1 and 30.8% fat, and muscle/bone ratios were 2.79 and 2.97, respectively.

3. Effects of oats and barley in high grain rations on total and proportions of muscle, bone and fat

In Table 7, for two groups of Jersey bulls are presented age at slaughter, live weight, carcass weight and carcass composition. Group 1 was fed oats and Group 2 barley as previously outlined. Group 1 carcasses contained more total and proportion of lean than Group 2 ($P < 0.01$), greater

TABLE 7

Cold carcass weights, age and live weights at slaughter with means, standard deviations and percentages of muscle, bone and fat and muscle/bone ratio from dissection of half carcasses from two groups of Jersey (JR) bulls.

Group[3]	Cold Carcass wt. kg.	Age (days)	Live Weight kg.	Muscle		Bone		Fat		Muscle/Bone Ratio
				kg.	%	kg.	%	kg.	%	
1. JR (oats) (4)[1]	71.2 ±4.5	400	290.6	48.4 ±3.5	68.8 ±1.4	11.0 ±0.6	15.6 ±0.6	10.5 ±1.1	14.9 ±1.2	4.4 ±0.2
2. JR (barley) (4)	74.8 ±9.3	413	297.4	45.6 ±5.2	61.8 ±0.9	10.4 ±0.6	14.1 ±0.9	17.6 ±3.6	23.6 ±1.7	4.4 ±0.2
Variance ratio for group means[2]	0.4			0.6	55.7**	1.6	6.2	10.8*	50.0**	0.1

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1 Numbers in parenthesis indicate number of animals in each treatment.

2 1 and 6 degrees of freedom.

3 Group 1 and Group 2 treatments were rolled oats and rolled barley respectively.

* Significant at $P < 0.05$.

** Not significant at $P < 0.01$.

amount of total and proportion of bone over Group 2 (though not statistically significant) and lesser amounts of total and proportion of fat compared to Group 2. However, muscle/bone ratios were virtually the same in both groups.

Group 2 fed barley consumed 2% more feed daily (Grieve 1968) than Group 1 fed oats. In addition, barley contained more metabolizable energy per unit weight than oats (1282 vs. 1117 kcal/lb). Group 2 thus had more metabolizable energy available than Group 1 and the energy/protein ratio of the barley ration was higher than the oat ration (16.87 vs. 13.70 kcal/gram of protein). If protein supply in both the rations was adequate it would be metabolizable energy available in excess that would result in augmentation of deposition of fat in the animals fed barley.

Greater amount of fat in carcasses from animals fed barley can be supported by nutritional studies indicating that energy/protein ratio of the feed exerts a considerable influence upon fat deposition in the carcasses. These results are in good agreement with those obtained by Swanson (1951) in rats, Calloway and Spector (1955) in adult rats, Mayer (1956) and Sibbald _et al_. (1956) in weanling rats, Hill and Dansky (1956) and Peterson _et al_. (1954) in chickens.

Similarly, working with pigs Clausen (1961) showed that with increase in the feeding level (metabolizable energy intake) the proportion of lean in the carcass fell and the amount of fat deposited increased. Blaxter (1952) observed in dairy cattle that with increasing metabolizable energy, protein synthesis increased at an ever-diminishing rate, whereas fat deposition increased at an ever-increasing rate.

The extra fat deposition in animals fed barley could also be explained from the estimates of energy cost of protein and fat deposition in young growing animals. Kielanowski (1965) working with young lambs derived a multiple regression equation relating intake of metabolizable

energy in kcal ($\hat{Y}$) with days on test (X_D), deposition of protein in grams (X_P) and storage of fat in grams (X_F):

$$\hat{Y} = 405.05X_D + 7.07X_P + 14.97X_F$$

$$n = 6;\ R = 0.984\ (P < 0.05)$$

In this equation, the first partial regression coefficient represents the average daily expenditure of kcal metabolizable energy on maintenance, and the second and third coefficients represent the expenditure of kcal metabolizable energy on the deposition of 1 gram of protein and fat respectively. The energy requirement for maintenance in both the groups would be expected to be the same as they were practically of the same age and weight and were exposed to similar environmental influences. The energy cost of protein synthesis in young mammals has been claimed to be uniform ranging between 7-8 kcal of metabolizable energy per 1 gram of protein synthesis and the energy cost for fat deposition about 15 kcal per 1 gram (Kielanowski, 1965). On the basis of the above relationship, it could be inferred that the barley ration provided enough metabolizable energy above maintenance and growth to bring about the increase in the amount of dissectable fat in the carcasses compared to animals fed oats.

B. Relationships involving total muscle, muscle/bone ratio and percentage fat in steers, bulls and heifers

1. Relationships involving total muscle

In Tables 8, 9 and 10 are shown the regressions and correlations involving total muscle, bone and fat, total muscle plus bone and cold carcass weights in bulls, steers and heifers, respectively. The regressions and correlations of total muscle on total bone were positive and generally significant in all sexes. In a few groups the relationship was not significant but this may have been a result of more uniform

TABLE 8

Simple linear regression (b) and correlation coefficients (r) with muscle weight, muscle/bone ratio and percentage fat as dependent variables based on dissection data from fifty-nine bulls

Dependent Variable		Muscle Weight				Muscle/Bone Ratio					Percentage Fat				
Independent Variable		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Group															
1. HY	b	6.65**	0.94	0.91**	0.71**	0.03**	0.09	0.01	0.02**	0.02**	-.08	-.13	0.38**	-.06	-.01
(17)[1]	r	0.82**	0.40	0.99**	0.95**	0.80**	0.31	0.03	0.76**	0.63**	-.34	-.07	0.72**	-.32	-.03
2. HY (C.A.G.) X HE	b	4.68	0.64	0.88**	0.41*	0.02	0.01	0.01	0.02	0.01	0.30	2.56*	0.37**	0.29	0.18*
(5)	r	0.79	0.78	0.99**	0.93*	0.62	0.01	0.04	0.54	0.29	0.66	0.95*	0.99**	0.72	0.89*
3. HE	b	5.17**	0.55**	0.87**	0.41**	0.02	-.01	0.01	0.01	0.01	0.28	1.66	0.42**	0.25	0.20**
(13)	r	0.85**	0.70**	0.99**	0.91**	0.52	-.02	0.24	0.45	0.33	0.50	0.49	0.96**	0.51	0.80**
4. HL	b	2.48*	1.29	0.77**	0.57**	-.01	-.09	0.01	-.01	-.01	0.09	0.06	0.58**	0.06	0.08
(8)	r	0.81*	0.65	0.99**	0.98**	-.07	-.65	0.14	-.22	-.16	0.29	0.06	0.91**	0.25	0.42
5. SH Cross	b	5.53**	2.18**	0.87**	0.65**	0.02	0.05	0.03	0.02	0.01	0.09	0.74*	0.33*	0.08	0.07
(8)	r	0.91**	0.92**	0.99**	0.99**	0.62	0.22	0.35	0.57	0.50	0.54	0.72*	0.83*	0.56	0.66
6. JR	b	5.93**	0.25	0.88**	0.51*	0.04*	0.15	0.02	0.03*	0.02*	-.11	-1.69	0.97**	-.11	0.28
(8)	r	0.87**	0.24	0.99**	0.83*	0.82*	0.44	0.36	0.79*	0.75*	-.11	- .25	0.93**	-.13	0.46
Variance ratio:															
Among group regressions		7.86**	11.20**	1.01	5.21**	1.21	6.53**	2.00	1.05	2.02	1.65	2.10	4.30**	1.90	3.98**
Among adjusted group means[2]		----	----	17.20**	----	13.53**	----	7.48**	9.43**	8.17**	10.05**	11.43**	----	10.17**	----

1 Numbers in the parentheses indicate number of animals.
2 Group means of dependent variable adjusted for independent variable by covariance. Missing values mean covariance analysis not legitimate.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

TABLE 9

Simple linear regression (b) and correlation coefficients (r) with muscle weight, muscle/bone ratio and percentage fat as dependent variables based on dissection data from ninety-one steers .

Dependent Variable		Muscle Weight				Muscle/Bone Ratio					Percentage Fat				
Independent Variable		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Group															
1. BS Cross	b	4.41**	0.85*	0.85**	0.57**	0.02*	0.01	0.01	0.01	0.01	0.01	0.04	0.40**	0.01	0.07
(14)[1]	r	0.87**	0.57*	0.99**	0.94**	0.55*	0.07	0.27	0.48	0.44	0.02	0.03	0.82**	0.01	0.33
2. HY (C.A.G.) X HE	b	4.65**	-.23	0.85**	0.41*	0.01	- .01	- .01	0.01	0.01	-.45**	-1.95*	0.57**	-.38	0.12
(16)	r	0.89**	-.26	0.99**	0.60*	0.43	-0.03	-0.23	0.36	0.09	-.63**	- .52*	0.91**	-.62	-.25
3. HY	b	3.10**	0.37*	0.84**	0.39**	0.01	- .10	0.01	0.01	0.01	0.09	-0.32	0.44**	0.06	0.19*
(16)	r	0.71**	0.50*	0.99**	0.84**	0.29	- .47	0.26	0.16	0.21	0.14	- .11	0.91**	0.1	0.62*
4. HL	b	0.44	0.25	0.93**	0.30	0.05	- .20	- .01	0.04	0.01	0.33	4.22**	0.56**	0.52	0.37
(5)	r	0.11	0.47	0.97**	0.73	0.69	- .64	- .31	0.51	0.02	0.32	0.97**	0.99**	0.52	0.87
5. HE X HY (C.A.G.)	b	1.70	0.56	0.82**	0.47**	0.02	- .16	0.04	0.01	0.01	0.28	- .45	0.59**	0.17	0.24
(8)	r	0.52	0.63	0.98**	0.93**	0.28	-0.67	0.56	0.06	0.31	0.42	- .20	0.97**	0.30	0.69
6. HE X HY (A.G.)	b	2.56	0.13	0.93**	0.27*	0.05**	- .17	0.01	0.04*	0.01	0.03	-1.17	0.54**	0.01	0.35**
(13)	r	0.37	0.24	0.99**	0.61*	0.73**	- .37	0.21	0.63*	0.42	0.03	- .17	0.97**	0.01	0.79**
7. HE	b	3.22**	0.08	0.83**	0.24*	0.01	- .12	0.01	-.01	0.01	-.20	-1.18	0.57**	-.18	0.29*
(11)	r	0.79**	0.15	0.99**	0.62*	0.08	- .55	0.17	-.05	0.12	-.17	- .25	0.95**	-.19	0.65*
8. SH Cross	b	5.26**	1.82**	0.85**	0.60**	0.13*	0.06	0.02	0.01	0.01	0.04	0.27	0.18	0.03	0.03
(8)	r	0.97**	0.94**	0.99**	0.99**	0.71*	0.54	0.57	0.69	0.65	0.23	0.29	0.54	0.24	0.33
Variance ratio:															
Among group regressions		4.50**	9.03**	1.91	5.31**	1.02	3.93**	2.10	0.68	0.89	1.5	2.01	8.7 **	1.00	4.5 **
Among adjusted group means[2]		----	----	8.41**	---	9.83**	----	5.81**	8.74**	7.77**	4.58**	4.19**	----	4.57**	----

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1 Numbers in the parentheses indicate number of animals.

2 Group means of dependent variable adjusted for independent variable by covariance. Missing values mean covariance analysis not legitimate.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

TABLE 10

Simple linear regression (b) and correlation coefficients (r) with muscle weight, muscle/bone ratio and percentage fat as dependent variables based on dissection data from eighteen heifers

Dependent Variable		Muscle Weight				Muscle/Bone Ratio					Percentage Fat				
Independent Variable		Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight	Muscle	Bone	Fat	Muscle + Bone	Cold Carcass Weight
Group															
1. HE	b	4.12**	0.73	0.84**	0.79**	0.02	-.04	0.04	0.01	0.01	-.31*	-1.55	0.60	-.27*	-.23*
(10)[1]	r	0.88**	0.25	0.99**	0.99**	0.34	-.14	0.29	0.26	0.29	-.72*	- .72*	0.48	-.74*	-.67*
2.															
2. SH Cross	b	4.05	0.81**	0.96**	0.47**	0.09**	-.01	0.08**	0.08**	0.04	0.46	-1.34	0.57**	0.57**	0.27**
(8)	r	0.41	0.89**	0.99**	0.97**	0.91**	-.01	0.93**	0.87**	0.93	0.70	- .18	0.94**	0.66	0.84**
Variance ratio:															
Among group regressions		5.35*	7.60*	2.10	5.61*	1.21	6.21*	1.00	1.56	1.31	3.14	4.00	5.20*	2.11	4.78*
Among adjusted group means[2]		----	----	8.61**	----	5.51*	----	6.10*	5.67*	4.59*	4.59*	6.39*	----	4.60*	----

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[1] Numbers in parentheses indicate number of animals.

[2] Group means of dependent variable adjusted for independent variable by covariance. Missing values mean covariance analysis not legitimate.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

slaughter weights or confounding with year effects. However, the regression coefficients among groups differed significantly ($P < 0.01$) among bulls, steers and heifers. Phrased in other words, the growth impetus for muscle in diverse genetic groups of bulls, steers and heifers were significantly different. Moreover, the pooled regression coefficients were 5.68, 4.43 and 4.01 in bulls, steers and heifers indicating a greater increase in muscle growth relative to bone, though non-significant, in bulls, followed by steers and heifers.

Relationships involving muscle and fat were much more variable. In this study, the younger bulls (Groups 2 and 5), steers (Groups 1, 3 and 8) and heifers (Group 2) showed significant ($P < 0.01$ or $P < 0.05$) regression and correlation coefficients for muscle on fat. Only one group of steers (Group 2) showed a negative relationship because of within group confounding between years with respect to these two variables (1966 animals were larger but had less fat than those from 1967). It should be mentioned here that comparatively older bulls (Groups 1, 3, 4 and 6), steers (Groups 4, 5 and 6) and heifers (Group 1) did not reach significance levels probably because of less variation in carcass weight. As expected, among group regressions of muscle on fat differed significantly ($P < 0.01$) within all three sexes, indicating variations of dissectible fat in the carcasses relative to amount of muscle.

Since muscle is a part of muscle plus bone and since muscle is correlated with bone, it is not surprising to see highly significant ($P < 0.01$) regression and correlation coefficients between muscle and muscle plus bone in each group of three different sexes. The among group regression coefficients of muscle on muscle plus bone were not significantly ($P < 0.01$) variable within bulls, steers or heifers indicating that these

slopes (group regression coefficients) are homogenous.

The relationships of muscle to cold carcass weight were significant ($P < 0.01$ or $P < 0.05$) in all breed groups except one. The regression coefficients differed significantly ($P < 0.01$) among groups in bulls, steers and heifers. Implicit in this is the indication of a difference among the groups in muscle increase relative to cold carcass weight increase.

In the present study, analysis of muscle weight by covariance adjustment would not be appropriate in 3 of 4 cases. The two basic assumptions underlying covariance analysis are: (a) that there be no confounding among the groups with respect to the treatment combinations and (b) that the among-group regression coefficients should be homogeneous. The first limitation should not be serious since confounding would only tend to reduce the level of significance among groups for the dependent variable. The second limitation, however, would eliminate the feasibility of establishing a pooled adjustment factor of the dependent variable based on the independent. With respect to total muscle, the only independent variable which might therefore be used for adjustment by covariance is total muscle plus bone.

Adjustment by covariance of group muscle means (Tables 8, 9 and 10) for variations in total muscle plus bone increased the variance ratio for testing difference among adjusted means compared to unadjusted means. This indicates there are significant differences between the groups in total muscle weight even after adjustment is made for differences in muscle plus bone. These results are in good agreement with Berg and Butterfield (1966).

2. Relationships involving muscle/bone ratio

Tables 8, 9 and 10 also relate muscle/bone ratio to muscle, bone, fat, muscle plus bone and cold carcass weight in bulls, steers and heifers, respectively. In general an increase in all the independent variables except bone resulted in an increase in muscle/bone ratio as indicated by positive regression coefficients. However, the pooled regression coefficients of muscle/bone ratio on muscle were 0.023, 0.018 and 0.011 in bulls, steers and heifers respectively. This appeared to indicate that the rate of rise of muscle/bone ratio as the total muscle increased was higher in bulls followed by steers then heifers.

The relation of muscle/bone ratio to bone was positive, though not significant, in comparatively younger bulls (Groups 1, 2, 5 and 6) and steers (Groups 1 and 8). Both groups of heifers, although young, and the older groups of bulls (Groups 3 and 4) and steers (Groups 2, 7, 4, 5, 6 and 7) showed a negative relationship. This appeared to indicate that heifers mature at lighter weights compared to bulls and steers.

The regression of muscle/bone ratio on bone was heterogeneous among groups of bulls, steers and heifers. Covariance involving muscle/bone ratio adjusted to common weights of bone was therefore not legitimate. However, the present study indicated statistically significant differences in muscle/bone ratio among breed groups of bulls, steers and heifers even after adjustment was made for muscle, bone, fat, muscle plus bone or cold carcass weight. Breed differences in muscle/bone ratio have been cited by Berg and Butterfield (1966), Hankins, Knapp and Phillips (1942) and by Carrol _et al_. (1964).

3. Relationships involving percentage fat

Percentage fat tended to increase as cold carcass weight and various tissues increased in different breeds of bulls, steers and heifers,

indicated by positive regression coefficients in Tables 8, 9 and 10 respectively. This was probably a reflection of the tendency of heavier animals to have been fatter and of fat deposition to have been rapid relative to other tissues over the range of these data. The relationship of percent fat to other tissues was not high in most cases and the relationship to muscle and muscle plus bone turned out to be negative in breed groups 1 and 6 of bulls, 2 and 7 of steers and 1 of heifers. This was due to the fact that there was within group confounding between years (1966-1967).

The regression and correlation coefficients between percent fat and cold carcass weight in diverse breed groups of three sexes were variable but positive except in breed groups 1 of bulls and heifers due to within group confounding between years (1966-1967) with respect to the variables involved. However, there was a singificant ($P < 0.01$) difference among group regressions of percentage fat on fat and on cold carcass weight which indicated that for a given increase in weight of fat tissue or cold carcass weight, there was a variable increase in fat percentage among groups.

C. Growth coefficients for muscle, bone and fat from diverse breed groups of bulls, steers and heifers

The relation of muscle, bone and fat to total muscle plus bone has been calculated on a double logarithmic scale. The regression coefficients (b) indicate the proportionate growth of muscle, bone and fat to muscle plus bone and can be referred to as growth coefficients (Huxley, 1932 as cited by Elsley *et al.*, 1964).

1. Growth coefficient for muscle

The growth coefficients for muscle did not differ significantly among different breed groups of bulls (Table 11), steers (Table 12) and heifers (Table 13). These coefficients for muscle (within sex pooled "b") were 1.09, 1.06 and 1.04 in bulls, steers and heifers respectively. The deviations from regressions in growth coefficients for muscle are quite small in all breed groups of steers, bulls and heifers. These observations are in good agreement with those of Berg and Butterfield (1966) in different breeds of steers, Tulloh (1963) in cattle, pigs and sheep and Elsley _et al_. (1964) in pigs and sheep.

The influence of sex on growth coefficients for muscle was determined within breed groups and was not significantly different among sex groups of HE, SH cross, HY and HY (C.A.G.) X HE breeds (Table 14). However, the growth coefficients for muscle were higher in all comparisons for bulls compared to steers and steers compared to heifers. Thus bulls appeared to have a prolonged growth impetus for muscle over steers and steers over heifers.

2. Growth coefficients for bone

Growth coefficients for bone did not show a significant difference among different breed groups of bulls (Table 11), steers (Table 12) or heifers (Table 13). The growth coefficients for bone (within sex pooled "b") were 0.55, 0.69 and 0.84 in bulls, steers and heifers respectively. This would also mean that there is a constant differential growth ratio between weight of carcass bone and muscle plus bone. The slopes of these lines (pooled values of "b") ranged between 0.55 and 0.84 and being less than 1.0 indicated that the proportion of bone falls as muscle plus bone increases. The deviation from regressions in growth coefficients for

TABLE 11

Estimates of growth coefficients (b) from the relationship $\log_{10}Y = a + b \log_{10}X$, where X = (Muscle + Bone), based on dissection data from fifty-nine bulls

(Y)	Dependent Variable					
Group	Muscle		Bone		Fat	
	b	S.E. of b	b	S.E. of b	b	S.E. of b
1. HY (17)[1]	1.07	0.02	0.61	0.09	0.58	0.34
2. HY (C.A.G) X HE (5)	1.06	0.05	0.72	0.25	2.38	0.75
3. HE (13)	1.04	0.02	0.78	0.13	2.23	0.61
4. HL (8)	1.14	0.06	0.76	0.26	1.49	0.85
5. SH Cross (8)	1.06	0.03	0.67	0.03	1.36	0.21
6. JR (8)	1.08	0.26	0.64	0.12	0.40	1.34
Variance ratio: Among-group regressions[2]	0.85		0.67		1.90	

---

[1] Number in parentheses indicate number of animals.

[2] 5 and 47 degrees of freedom.

TABLE 12

Estimates of growth coefficients (b) from the relationship $\log_{10}Y = a + b \log_{10}X$, where X = (Muscle + Bone), based on dissection data from ninety-one steers

(Y)	Dependent Variable					
Group	Muscle		Bone		Fat	
	b	S.E. of b	b	S.E. of b	b	S.E. of b
1. BS cross (14)[1]	1.05	0.24	0.78	0.11	1.01	0.40
2. HY (C.A.G) X HE (16)	1.03	0.02	0.86	0.09	-0.61	0.54
3. HY (16)	1.02	0.04	0.92	0.17	1.23	0.65
4. HL (5)	1.15	0.16	0.39	0.62	3.57	2.21
5. HE X HY (C.A.G) (8)	1.01	0.09	0.92	0.39	2.04	0.99
6. HE X HY (A.G) (13)	1.13	0.05	0.38	0.22	1.15	1.17
7. HE (11)	1.03	0.04	0.81	0.18	0.36	1.04
8. SH Cross (8)	1.03	0.01	0.86	0.06	1.11	0.18
Variance ratio: Among-group regressions[2]	1.77		0.73		1.48	

---

[1] Number in parentheses indicate number of animals.

[2] 7 and 75 degrees of freedom.

TABLE 13

Estimates of growth coefficients (b) from the relationship $\log_{10}Y = a + b \log_{10}X$, where X = (Muscle + Bone), based on dissection data from eighteen heifers

(Y)	Dependent Variable					
Group	Muscle		Bone		Fat	
	b	S.E. of b	b	S.E. of b	b	S.E. of b
1. He (10)[1]	1.03	0.03	0.71	0.15	1.19	0.23
2. SH cross (8)	1.04	0.04	0.67	0.18	2.05	0.56
Variance ratio: Among-group regressions[2]	1.01		0.56		2.13	

---

[1] Number in parentheses indicate number of animals.

[2] 1 and 14 degrees of freedom.

TABLE 14

Among sex-group test of significant differences of growth coefficients for muscle, bone and fat

Breed	HE				SH CROSS				HY			HY (C.A.G.) X HE		
Sex-group	BULLS	STEERS	HEIFERS	Sig.[1] Level	BULLS	STEERS	HEIFERS	Sig. Level	BULLS	STEERS	Sig. Level	BULLS	STEERS	Sig. Level
Number of animals	13	11	10		8	8	8		17	16		5	16	
Live weight (kg.)	466.2	373.9	305.5		322.3	310.4	276.9		496.5	461.5		470.3	461.8	
1. Growth coefficients (Muscle)	1.03	1.02	1.01	3.24	1.05	1.03	1.02	2.43	1.07	1.02	0.01	1.06	1.03	0.53
2. Growth coefficients (Bone)	0.78	0.89	0.90	3.31	0.75	0.81	0.87	3.21	0.61	0.91	4.01	0.72	0.86	0.47
3. Growth coefficients (Fat)	1.10	1.58	2.22	5.50**	1.12	1.36	2.05	4.96*	1.23	1.38	5.20*	1.21	2.37	9.01**

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[1] Variance ratios: among sex-group regressions.

* Significant at $P<0.05$.

** Significant at $P<0.01$.

bone in all the breed groups in three sexes were small. The results of the present study are in agreement with those of Berg and Butterfield (1966), Elsley et al. (1964) and Tulloh (1963).

Growth coefficients for bone did not differ significantly among sex groups of four different breeds (Table 14). Though statistically non-significant, growth coefficients for bone tended to be low in bulls compared to steers and steers compared to heifers over the range of these data.

The net result of higher growth coefficients for muscle and lower coefficients for bone in bulls compared to steers and steers compared to heifers, explains the basis for higher muscle/bone ratios in bulls over steers and steers over heifers.

3. Growth coefficients for fat

Among breed groups growth coefficients for fat were not significantly different in bulls (Table 11), steers (Table 12) or heifers (Table 13). The growth coefficients for fat (within sex pooled "b") were 1.10, 1.18 and 2.38 in bulls, steers and heifers respectively. (These data also suggested a constant differential growth ratio between weight of dissected carcass fat and muscle plus bone). The slopes (pooled values of "b") were 1.10 or more indicating that the proportion of fat in a carcass increased relative to muscle plus bone over the range of these data. The deviations from the regressions in all breed groups were high, indicating individual variations in the degree of fatness. Efforts to change body composition might well be directed toward altering the value of "b" for fat. These results corroborated the findings of Berg and Butterfield (1966), Elsley et al. (1964) and Tulloh (1963).

The coefficients for fat were significantly ($P < 0.01$ or $P < 0.05$) different among sex groups of 4 different breeds (Table 14). The slopes

(regression coefficients for fat in Table 14) in heifers, even at considerably lighter live weights, were higher compared to steers and steers compared to bulls in all four breed groups.

These results indicate that the 3 sexes studied follow different patterns of fattening, probably with respect to both onset and rate of fattening.

SUMMARY AND CONCLUSIONS

The present research project was designed to investigate the influence of breed, sex and nutrition on the growth patterns of muscle, bone and fat in 168 beef cattle consisting of 91 steers, 59 bulls and 18 heifers representing 8, 6 and 2 breed groups respectively. The total and proportion of muscle, bone, fat and muscle/bone ratio was significantly ($P < 0.01$) different among breed groups of bulls and steers without showing any such difference between two breeds of heifers. Breeds and crosses which differ in growth patterns and development of tissues could thus be judiciously utilized for the economic production of beef in such a way that optimum carcass composition would result.

Sex imparted a marked influence on the onset of fattening with heifers fattening at lighter live weights than steers and steers at lighter weights than intact males. This emphasises that bulls have a higher growth impetus for muscle compared to steers and steers compared to heifers. The bulls are favoured in muscle/bone ratio over steers and steers over heifers. This seems to indicate that the slaughter of animals of different sexes at a constant live weight is not legitimate for comparison of carcass composition. However, similarity in the proportions of major tissues in the carcass could be brought about by shifting the slaughter weight in different sexes.

Nutrition exerted its major influence on the carcass composition through its distribution of metabolizable energy consumed for the synthesis of new tissues. In young growing animals when the energy for maintenance and protein synthesis is met, the extra energy consumed is utilized for the deposition of fat. This explains why Jersey bull calves fed barley contained more fat, less lean and a similar proportion of bone compared to those fed oats, although they were of same age and

showed equal rate of gain and feed efficiency. However, it has been well established that the limitation of protein synthesis from consumed metabolizable energy differs among breeds and could be improved by selection.

The simple regression and correlation coefficients involving muscle, bone and dissectable fat, muscle/bone ratio and cold carcass weight were estimated to find a suitable index for the genetic merit of carcass composition which would be either almost independent of live weight or stage of physiological maturity or one in which adjustment to a common basis would be simple and statistically satisfactory. Breed differences in total muscle remained when variation in total muscle plus bone was removed. This indicates that selection for meatiness could be proposed on the basis of the test criterion. Muscle/bone ratio may prove to be a statistically sound and a useful tool in the hands of breeders for comparing the genetic merit of animals at a standardized weight. Groups of animals differing in carcass weight could be compared through muscle/bone ratio if the rate of change of this ratio against adjusted carcass weight in a breed is estimated and adjusted for.

Fat was found to be highly influenced by breed, sex and nutrition. Percentage of fat increased with increased carcass weight. However, there was a considerable variation among groups in the rate of deposition of fat per unit increase in carcass weight.

Growth coefficients for muscle, bone and fat, based on a logarithmic relationship with total muscle plus bone was found to be appropriate for describing the relative change in one part of animal compared to another suitable part or parts of the body. The pooled growth coefficients were 1.08 for muscle, 0.87 for bone and 2.01 for fat. The standard error in growth coefficients of fat was comparatively great indicating that fat was a highly variable component of the body. Thus effort to change body

composition may be aimed at altering the rate of fat deposition. This also justifies the exclusion of fat from the independent variable in the allometric equation.

Sex seemed to influence the size of growth coefficients. Within a breed coefficients for bulls were higher for muscle and lower for bone which were followed by steers and then heifers. This explains why the bulls were favoured in muscle/bone ratio over steers and steers over heifers. Furthermore, the onset and rate of fattening was not uniform in the 3 sexes, bulls having a low coefficient, steers intermediate and heifers high.

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APPENDIX TABLE 1

Experimental animals with codes used to indicate breed groups, sex, source and number of animals in each group

Breed Groups	Codes used for breed groups	Source		
		Steers	Bulls	Heifers
1. Brown Swiss Cross	BS Cross	Kinsella[3] (14)[5]	--------	---------
2. Hybrid (C.A.G)[1] X Hereford	HY (C.A.G) X HE	Kinsella (16)	Kinsella (5)	---------
3. Hybrid	HY	Kinsella (16)	Kinsella (17)	---------
4. Holstein	HL	Kinsella (5)	Dairy Herd[4] (8)	---------
5. Hereford X Hybrid (C.A.G)	HE X HY (C.A.G)	Kinsella (8)	----------	---------
6. Hereford X Hybrid (A.G)[2]	HE X HY (A.G)	Kinsella (13)	----------	---------
7. Hereford	HE	ABCPA (11)	Kinsella (13)	ABCPA (10)
8. Shorthorn Cross	SH Cross	Kinsella (8)	Kinsella (8)	Kinsella (8)
9. Jersey	JR	------------	Dairy Herd (8)	---------

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[1] C.A.G means Charolais . Angus . Galloway.

[2] A.G. means Angus . Galloway.

[3] The U. of A. beef breeding ranch is located at Kinsella, Alberta.

[4] Dairy research herd of U. of A.

[5] Numbers in the parentheses indicate number of animals in each breed group.

APPENDIX TABLE 2

Approximate formulation and composition[1] of the ration for Kinsella herd in 1965

Ingredients	% of Concentrate
Cut hay	Free choice
Rolled barley	75.0
Rolled oats	18.5
Soybean meal	5
Cobaltized-Iodized salt	0.5
Limestone	0.5
Bone meal	0.5
	100

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[1] Contained 3000 I.U. Vitamin A and 700 I.U. Vitamin D per lb. feed.

APPENDIX TABLE 3

Formulation and composition[1] of pelleted supplement for Kinsella herd in 1966 and 1967

Ingredients	%
Soybean oil meal	71.75
Cobaltized-Iodized salt	7.5
Di-calcium phosphate	7.5
Ground Limestone	7.5
Dried molasses	5.75
	100

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[1] Contained 80,000 I.U. Vitamin A and 2,000 I.U. Vitamin D for lb. of supplement.

APPENDIX TABLE 4

Design of Feeding Holstein Bulls

Adjustment Period	Group 1	Group 2
Grain	Rolled Barley	Whole Barley
Duration	49 days	29 days
1st eight weeks	Rolled barley	Whole barley
2nd eight weeks	Whole barley	Rolled barley
3rd eight weeks	Rolled oats	Whole oats
4th eight weeks	Whole oats	Rolled oats

APPENDIX TABLE 5

Formulation and composition[1] of pelleted supplement for Holstein and Jersey bulls

Ingredients	%
Urea	27
Dried Molasses	20
Shorts	17
Beet Pulp	16
Ground Limestone	7
Dicalcium phosphate	7
Cobaltized-Iodized salt	6
	100

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[1] Contained 53,000 I.U. Vitamin A and 13,000 I.U. Vitamin D per lb. of supplement.